West Virginia Seed Sources of Balsam Fir:

Between- and Within-Stand Variation in Characteristics of Half-Sib Families and Individual Progeny

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Steven A. Slack
Director

Ohio Agricultural Research and Development Center
1680 Madison Avenue
Wooster, Ohio 44691-4096
330-263-3700

Cover Photograph: Variations in form and density of trees of different seed sources of West Virginia balsam fir in the experimental planting at the North Appalachian Experimental Watershed Laboratory near Coshocton, Ohio. Note that trees have their natural form and have never been sheared.

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Introduction and Background

The taxonomy/identity of the *Abies* species in the eastern United States and Canada has been confusing. Taxonomists have traditionally recognized two species as being native to eastern North America. Balsam fir (*Abies balsamea* (L.) Mill.) has an extensive and more or less continuous natural range through Canada and southward into Minnesota, Wisconsin, Michigan, New York, and northern Pennsylvania, with disjunct distribution through central Pennsylvania and northern West Virginia and Virginia, while Fraser fir (*Abies fraseri* (Pursh) Poir.) occurs only at higher elevations in the mountains of southwestern Virginia, eastern Tennessee, and western North Carolina (Figure 1). The most prominent taxonomic feature used to distinguish between balsam and Fraser fir has been the relative length of the cone scales and bracts. For balsam fir, the bract is much shorter than and is fully enclosed within the cone scale, while in Fraser fir the bract is much longer than the cone scale and is exserted from the cone and reflexed downward. Attempts have also been made to differentiate between these two species on the basis of numbers of lines of stomata on the leaves and internal leaf anatomy, but individual variations make interpretations using those characteristics uncertain.

Some taxonomists have recognized two varieties of balsam fir, *A. balsamea* (L.) Mill. var. *balsamea*, the "typical" balsam fir and a "bracted" variety, *A. balsamea* (L.) Mill. var. *phanerolepis* Fern., which is distinguished from var. *balsamea* on the basis of the relative length of the bract and awn to length of the cone scale and by a slight variation in cone size. The range of var. *phanerolepis* has been identified as occurring within the range of var. *balsamea* at higher elevations in the mountains of the northeast, at lower elevations in Maine and the maritime provinces of Canada, as well as the small, isolated stands in the mountains of northern Virginia and West Virginia (Perry 1931, Fernald 1950, Little 1953).

Classification of the small populations of fir at higher elevations in northern West Virginia and Virginia (Figure 1) has been particularly confusing. Trees from those populations have cones similar to balsam fir as well as trees with exserted and reflexed bracts characteristic of Fraser fir and intermediate-appearing forms (Figure 2). These populations have, at various

James H. Brown, Professor Emeritus, School of Natural Resources, The Ohio State University, Ohio Agricultural Research and Development Center, Wooster, Ohio.

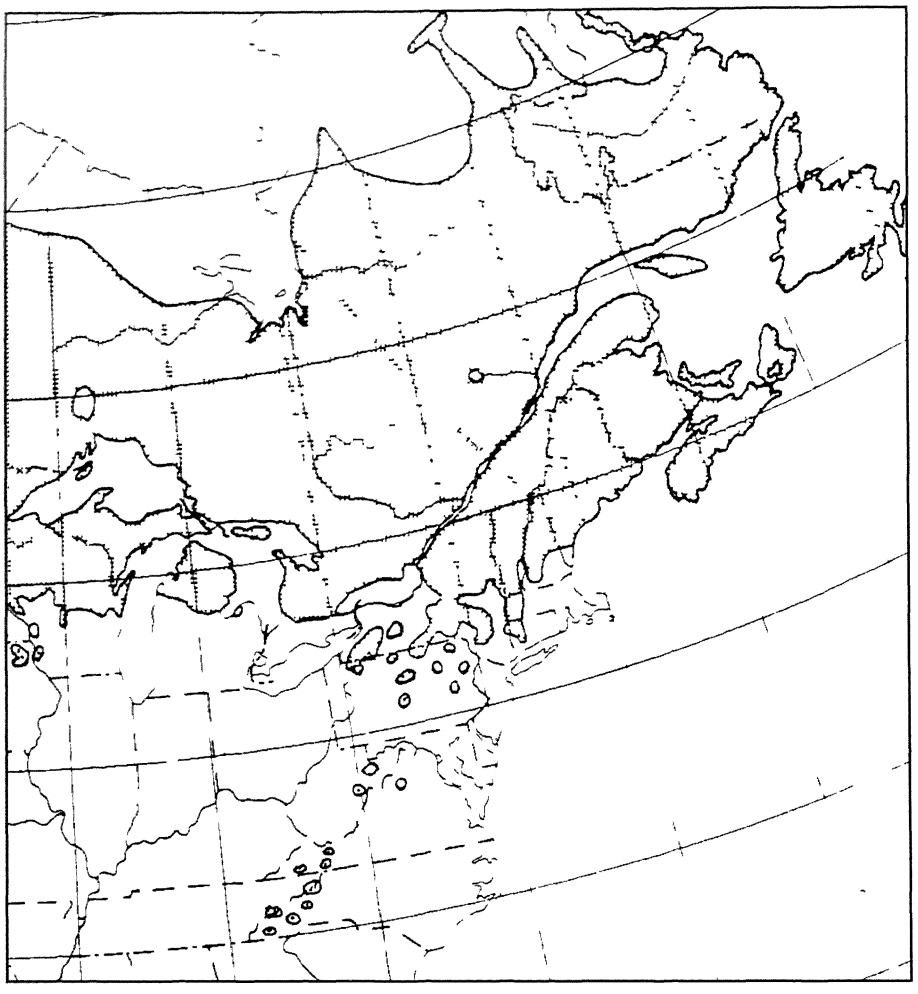

Figure 1. Natural range of the balsam fir *(Abies balsamea)* complex in the eastern United States and Canada.

times, been identified as *A. balsamea* (Millspaugh 1892, Core 1934, Core 1940), *A. fraseri* (Millspaugh 1913, Zon 1914, Brooks 1920, Fulling 1934, Wyman 1943), and *A. balsamea* var. *phanerolepis* (Perry 1931, Fosberg 1941, Fernald 1950, Little 1953, Strausbaugh and Core 1964), while Fulling (1936) and Core (1934) suggested that they might represent a separate species, *A. intermedia*, which was of hybrid origin between balsam and Fraser fir.

A number of studies have attempted to clarify the status of the *Abies* species in eastern North America. Oosting and Billings (1951) suggested that during the most recent glacial advance (Pleistocene), spruce-fir forests extended from Canada, south along the Appalachian Mountains to North Carolina and Tennessee, with a clinal pattern of phenotypic variation within that range. Since the glacial retreat, populations have become separated and have evolved to their present phenotypic expressions. Mark (1958) proposed that as the climate warmed, fir populations at lower elevations in the southern part of the range were replaced by other species, leaving only isolated stands at higher elevations. The gap between the *A. balsamea* and *A. fraseri* populations prevented gene flow from the northern populations, resulting in a reduction in the gene pool of *A. fraseri* during the recent xerothermic period, with genes responsible for phenotypes similar to *A. balsamea* being eliminated.

Myers and Bormann (1963) studied phenotypic variation in trees of *A. balsamea* var. *balsamea* and *A. balsamea* var. *phanerolepis* in response to altitudinal and geographic gradients in cone scale/bract ratios to measure

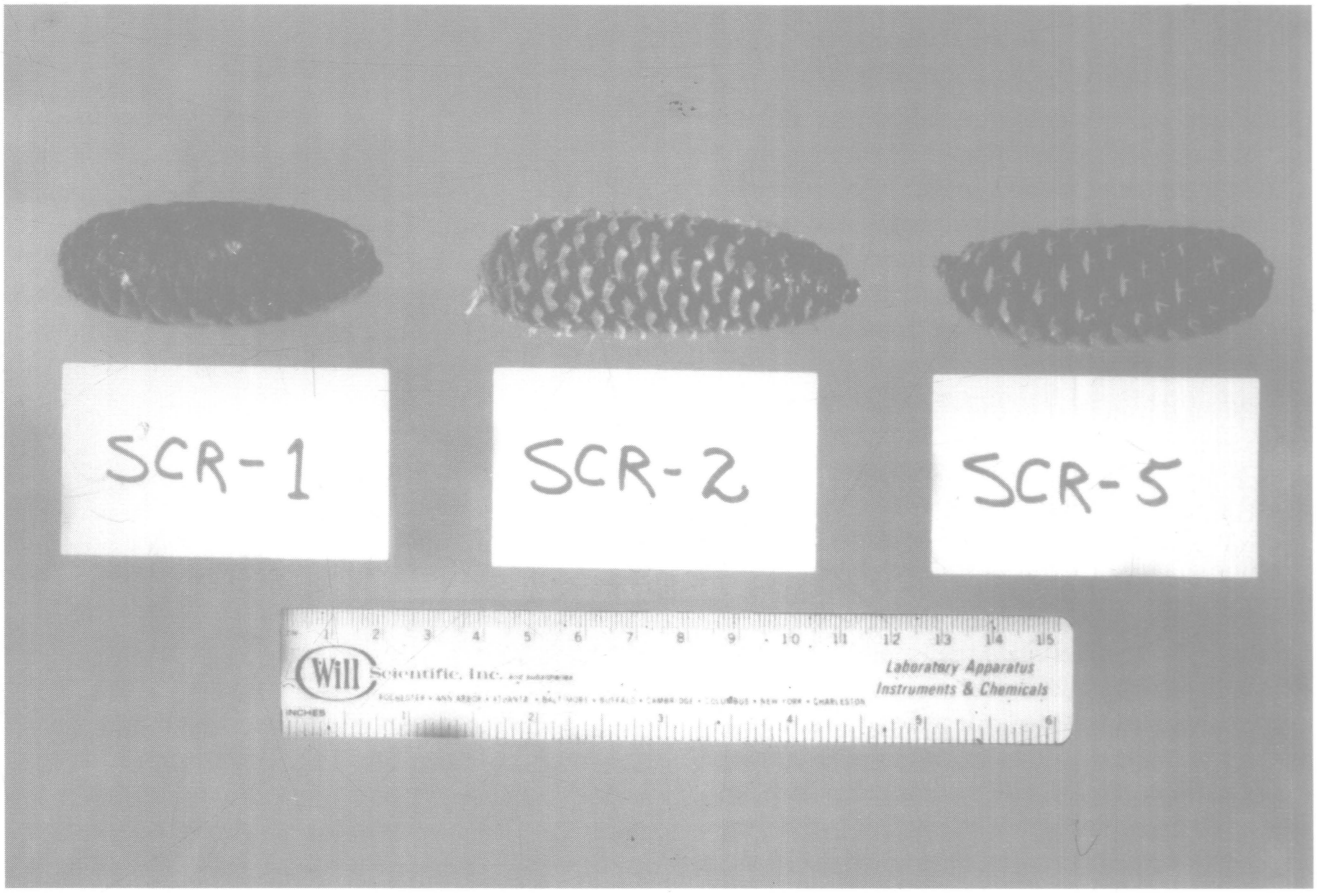

Figure 2. Cones from three trees of the Stone Coal Run collection, showing variations in bract length.

intergradation between the two varieties. Their studies found a complete series of morphological forms connecting the two, with two clines within the *A. balsamea* population — one from lower to higher altitudes in the mountains of the northeastern United States and one at lower altitudes from coastal regions toward the interior of the continent. Based on their data, they questioned the taxonomic validity of separation of *A. balsamea* into two varieties and also suggested that *A. balsamea* and *A. fraseri* represent closely related and recently separated populations. Studies by Robinson and Thor (1969) and Thor and Barnett (1974) compared various characteristics of trees from the "intermediate" populations of fir growing in northern West Virginia and Virginia with those of trees of Fraser fir from Virginia, North Carolina, and Tennessee and balsam fir from Pennsylvania and New York. They concluded that the "intermediate" populations were not of hybrid origin but rather are relicts of a once continuous fir population having clinal variation along a north-south gradient.

Thor and Barnett (1974) also proposed that only one species of *Abies* be recognized in eastern North America, with three varieties: var. *balsamea,* var. *phanerolepis* (including the northern Virginia and West Virginia populations), and var. *fraseri.*

Studies by Clarkson and Fairbrothers (1970) using serological and electrophoretic investigations of seed protein of trees also concluded that *A. balsamea* var. *balsamea* and *A. fraseri* are closely related and recently separated taxa and that *A. balsamea* var. *phanerolepis* (from the mountains of northern West Virginia and Vir-

ginia) is more closely related to *A. balsamea* than to *A. fraseri* and is not of hybrid origin. Studies by Jacobs *et al.* (1983), using electrophoretic study of seed proteins, came to similar conclusions; their study also found that electrophoretic patterns for seed of "bracted" sources from Canaan Valley, West Virginia, and Mt. Desert Island, Maine, were identical.

Previous Research

Research initiated in the early 1970s at The Ohio State University's Ohio Agricultural Research and Development Center (OSU/OARDC) found that trees of balsam fir grown from seed collected from stands in Canaan Valley, one of the isolated populations in the mountains of northern West Virginia, had a number of characteristics that made them desirable for planting as Christmas trees. Those characteristics included adaptability to somewhat "wetter" soils than trees of Fraser fir; later bud break on trees in the spring than those of Fraser fir and more northerly origins of balsam fir from Pennsylvania and New York; and more lateral limbs on shoots between major whorls than for trees of Fraser fir and the New York and Pennsylvania origins of balsam fir (Brown 1983). Subsequent research found that trees of the Canaan Valley origin also leafed out considerably later in the spring than trees of a Nova Scotia origin of balsam fir and somewhat later than those of Fraser fir (Brown 1998, Brown 1999).

As noted previously and as shown in Figure 4, small isolated populations of balsam fir occur at three locations in West Virginia in addition to those in Canaan Valley which were used in previous research at OSU/OARDC. It seemed probable that trees from those other stands might also have promise for use as Christmas trees. The purpose of the research reported here was to study genetic variation in trees from different stands and seed sources of balsam fir from the four West Virginia populations.

In this and previous research at OSU/OARDC, the taxonomic classification of balsam fir proposed by Thor and Barnett (1974), *Abies balsamea* var. *phanerolepis*, has been used to identify trees of the populations of balsam fir found in the mountains of northern West Virginia. **This should not be interpreted that results presented here and in other studies at OSU/OARDC relate to trees from other populations that might be identified as var. *phanerolepis*.**

Figure 3. Collecting cones from the tops of balsam fir.

Methods

In August 1981, seed was collected (Figure 3) from 15 trees in stands of balsam fir at four locations in West Virginia — Blister Run in Randolph County, Blister Swamp in Pocohontas County, Stone Coal Run in Tucker County, and Canaan Valley State Park in Tucker County. In the spring of 1984, an additional collection was made from 20 trees in a stand near Cortland Road north of the State Park in Canaan Valley (Figure 4; Table 1). Since one of the major

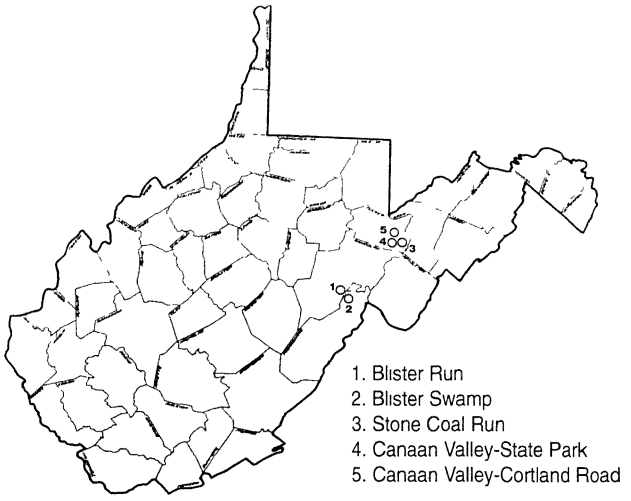

Figure 4. Locations of balsam fir stands in West Virginia.

objectives was to evaluate differences between and within areas, seed was collected and kept separate for individual trees (half-sib families) having a range of phenotypic characteristics at each location. Typically, the stands were located in or adjacent to bogs or swamps having small, running streams flowing through them; waters were not stagnant (Figure 5).

In the spring of 1983, seed of 10 half-sib families from each of the 1981 collections was seeded in flats filled with sterile sand in a greenhouse at the OSU/OARDC Wooster, Ohio, campus. In addition, seed of two stand collections of Fraser fir (*Abies balsamea* var. *fraseri*) from Roan Mountain, North Carolina seed sources, which had been purchased from commercial dealers, was seeded. These collections were included in the study to provide a reference for comparison of trees of the West Virginia sources of balsam fir with a species/variety that has been widely planted and accepted as a Christmas tree. Following germination, seedlings were transplanted into 2-inch x 2-inch x 10-inch open-ended paper containers that had been filled with potting mix. Seed of eight half-sib families of the Canaan Valley-Cortland Road collection were handled in the same way except they were seeded in the greenhouse in the fall of 1984.

The planting site for the study is located at the USDA North Appalachian Experimental Watershed Laboratory near Coshocton, Ohio. The area had been an old field that had not been used for field crops or pasture for several years but was mowed periodically to control briars and other woody vegetation. The site slopes gently to the southwest and the soil is classified as a moderately well-drained Coshocton silt loam, which formed in residuum of interbedded acid shales, siltstone, and coal underclays.

Prior to tree planting, three-foot-wide strips along planting rows were sprayed with glyphosate (2.5 quarts a.i.a.). After trees were planted,

Table 1. Locations of West Virginia Balsam Fir (*Abies balsamea* var. *phanerolepis*) Seed Collections Used in the Study of the Variation in Characteristics of Different Half-Sib Families and Individual Progeny.

Location		Latitude	Longitude	Elevation
Area	WV County	ºN	ºW	Ft.
Blister Run	Randolph	38.60	79.86	3,660
Blister Swamp	Pocahontas	38.68	79.67	3,630
Stone Coal Run	Tucker	39.02	79.38	3,670
Canaan Valley-State Park	Tucker	39.03	79.46	3,230
Canaan Valley-Cortland Road	Tucker	39.07	79.43	3,110

Figure 5. Natural stands of balsam fir at Blister Run (top) and Canaan Valley-Cortland Road (bottom).

areas within rows received annual applications of herbicides (simazine and atrazine, 2 pounds a.i.a. each); areas between rows were also mowed two or three times per year. Although the initial herbicide spraying killed most of the existing vegetation, there was substantial reinvasion/sprouting of woody species, particularly blackberry (*Rubus* sp.). Following planting, late summer applications of glyphosate and Garlon 3A were used to control that vegetation.

In the spring of 1985, trees of the 10 half-sib families from the first four West Virginia locations, plus the two Fraser fir stand collections, were planted. One-tree plots were used in each block (replication), with 10 feet between rows of trees and six feet between trees within rows. (This planting arrangement was used to accommodate conversion of the planting to a seed orchard at a later date.)

During planting, space was left at random locations in each block for adding trees of the eight half-sib families from the Canaan Valley-Cortland Road collection which were added to the planting in the spring of 1986. In all, there were 50 trees per block (48 half-sib families from the five West Virginia collections plus seedlings of the two Fraser fir stand collections), 24 blocks, and 1,200 total trees.

Periodic measurements and evaluations were made on individual trees, and statistical analyses were made using analyses of variance to test:

- Variation between half sib-families from different locations.
- Variation between all individual half-sib families.
- Variation within individual half-sib families.

In addition, correlation analyses were used to test the relationships between results of evaluations made in different years. When subjective ratings were used to rate tree shape and density, foliage colors and spring bud break, all evaluations were done by the author to minimize personal bias and perceptual differences.

Results and Discussion

Evaluations in the experimental planting revealed large variation in different traits of trees, not only for those from different areas (Figure 4; Table 1) but also between and within individual seed sources. Tables 2-7 provide summaries comparing averages and rankings for selected growth and foliage characteristics of trees of both vars. *phanerolepis* and *fraseri* from the six different areas from which seed collections were made. With the exception of bud development/foliage exposure comparisons in May 1996, all traits showed statistically significant differences between areas, and there were significant differences between seed sources for all traits.

Height Growth

As noted previously, trees of the Canaan Valley-Cortland Road collection were field-planted in 1986, one year after trees from the other five areas. To make heights of all trees comparable in statistical analyses, annual shoot growth for 1991 and 1996 was measured for individual Cortland Road trees, and those measurements were added to total heights that were measured in 1990 and 1995.

There was considerable reinvasion of vegetation into planting rows after trees were planted, as noted previously. As a consequence of competition from that vegetation, growth for the first few years was apparently reduced.

Differences Between Locations

Average, six-year heights of trees from different locations varied from 0.76 m for North Carolina source trees to 0.98 m for those from Canaan Valley-State Park, with the North Carolina trees being significantly smaller than those from the other areas (Table 2). Growth during the five-year period before the next set of measurements was made was much faster, with average heights of 11-year-old trees ranging from 3.08 m for North Carolina trees to 3.71 m for those from Stone Coal Run; again, there were no significant differences between the West Virginia origins (Table 2).

Table 2. Means, Standard Deviations, and Ranking of Heights, Taper, and Needle Lengths of Trees of Individual Half-Sib Families (West Virginia) and Stand Collections (North Carolina).

SS No.[1]	6-Yr. Height Mean m	6-Yr. Height S.D. % Mean	6-Yr. Height Rnk[3]	11-Yr. Height Mean m	11-Yr. Height S.D. % Mean	11-Yr. Height Rnk[3]	Taper[2] Mean %	Taper[2] S.D. % Mean	Taper[2] Rnk[3]	Needle Length Mean mm	Needle Length S.D. % Mean	Needle Length Rnk[3]
Blister Run, WV												
350	0.94	35	28	3.33	22	12	172	20	17	17.0	12	5
351	0.83	30	10	3.22	30	5	174	22	21	18.6	17	31
352	0.96	40	35	3.55	25	21	178	15	31	17.2	12	8
353	0.76	42	3	3.44	26	15	185	10	42	17.5	11	13
355	1.05	28	47	3.90	14	48	192	11	47	19.1	13	39
356	0.91	32	24	3.50	17	18	182	14	38	17.4	11	9
360	0.94	28	28	3.33	13	12	170	15	9	18.1	12	20
361	1.01	35	45	3.62	19	29	181	14	36	18.1	13	21
363	0.86	28	16	3.32	19	10	174	8	19	17.7	15	15
364	0.77	34	4	3.17	20	3	176	22	25	17.2	10	7
Mean	**0.90**	**11**	**4**	**3.44**	**20**	**3**	**179**	**13**	**4**	**17.8**	**12**	**2**
Blister Swamp, WV												
366	0.91	33	24	3.74	17	43	187	9	43	17.4	12	10
367	0.88	31	20	3.67	19	34	184	14	40	18.2	9	23
368	0.81	48	6	3.72	21	42	193	16	48	17.1	13	6
369	0.85	44	12	3.56	24	23	179	13	32	17.6	12	14
372	0.98	32	41	3.80	20	47	175	14	24	18.8	13	34
373	0.95	32	33	3.96	14	49	189	12	45	18.7	10	33
375	0.86	44	16	3.49	21	17	175	11	23	18.4	13	25
378	0.96	36	35	3.51	19	20	168	11	11	17.4	10	11
379	0.75	43	2	3.15	22	2	162	15	5	17.8	11	17
380	0.88	42	20	3.58	21	24	195	11	49	18.5	12	27
Mean	**0.88**	**8**	**3**	**3.62**	**20**	**5**	**180**	**14**	**5**	**18.0**	**12**	**3**
Stone Coal Run, WV												
381	0.85	41	12	3.79	14	46	188	12	44	18.5	14	30
384	0.95	31	33	3.71	17	41	195	14	50	17.7	11	16
385	0.91	38	24	3.67	14	35	184	13	41	19.9	10	48
386	0.93	40	27	3.66	20	33	179	13	28	18.0	15	18
387	0.88	38	20	3.69	16	35	189	12	46	19.2	15	41
389	1.16	28	50	3.99	15	50	176	11	26	19.4	16	42
390	0.96	35	35	3.58	17	24	177	11	27	21.5	12	50
393	0.97	30	40	3.69	12	38	174	10	22	16.5	8	3
394	0.83	35	10	3.55	17	21	181	10	35	16.6	10	4
395	0.94	43	28	3.75	22	44	179	13	33	18.4	13	24
Mean	**0.94**	**10**	**5**	**3.71**	**16**	**6**	**182**	**12**	**6**	**18.6**	**15**	**4**
Canaan Valley-State Park, WV												
397	0.98	34	41	3.36	24	14	165	13	8	19.6	13	46
398	0.94	40	28	3.61	16	27	178	10	30	19.0	10	36
399	1.11	32	49	3.68	15	37	162	10	4	19.1	11	39
400	1.03	33	46	3.69	17	38	166	12	9	19.4	11	44
402	0.96	38	35	3.32	25	10	165	15	7	17.5	10	12
403	0.87	41	19	3.58	17	24	166	14	10	18.1	8	19
404	1.10	29	48	3.69	19	38	178	13	29	18.9	14	35

Table 2 (continued). Means, Standard Deviations, and Ranking of Heights, Taper, and Needle Lengths of Trees of Individual Half-Sib Families (West Virginia) and Stand Collections (North Carolina).

SS No.[1]	6-Yr. Height Mean m	S.D. % Mean	Rnk[3]	11-Yr. Height Mean m	S.D. % Mean	Rnk[3]	Taper[2] Mean %	S.D. % Mean	Rnk[3]	Needle Length Mean mm	S.D. % Mean	Rnk[3]
406	0.97	32	40	3.50	19	18	163	13	6	18.7	14	32
408	0.96	31	35	3.64	19	32	180	11	34	18.6	9	28
409	0.86	33	16	3.29	17	9	173	9	18	18.4	14	26
Mean	**0.98**	**8**	**6**	**3.54**	**19**	**4**	**170**	**12**	**2**	**18.7**	**12**	**5**
Canaan Valley-Cortland Road, WV												
416	0.85	35	12	3.24	21	6	150	12	2	18.1	12	22
417	0.90	33	23	3.62	19	29	183	11	39	19.5	9	45
418	0.95	36	33	3.48	19	16	170	9	14	19.7	13	47
419	0.81	44	6	3.24	22	6	149	15	1	18.6	14	29
424	0.82	45	8	3.63	18	31	182	10	37	20.1	10	49
425	0.82	33	8	3.24	20	6	157	13	3	19.4	12	43
426	0.85	41	12	3.61	18	27	172	10	16	19.1	16	38
428	1.00	38	44	3.76	17	45	169	12	12	19.0	13	37
Mean	**0.88**	**8**	**2**	**3.43**	**22**	**2**	**166**	**13**	**1**	**19.2**	**17**	**6**
Roan Mountain, NC												
24	0.79	28	5	3.17	13	3	170	23	14	14.5	10	1
410	0.72	36	1	2.97	21	1	174	24	20	14.9	13	2
Mean	**0.76**	**6**	**1**	**3.08**	**25**	**1**	**172**	**13**	**3**	**14.7**	**12**	**1**
Variable Mean	**0.91**	--	--	**3.54**	--	--	**176**	--	--	**18.3**	--	--
Mean Comparisons Between Locations												
[4]pF:	<0.001	--	--	<0.001	--	--	0.002	--	--	<0.001	--	--
[5]$LSD_{0.05}$	0.11	--	--	0.24	--	--	11	--	--	1.11	--	--
Mean Comrarisons Among Individual Seed Sources												
[4]pF:	<0.001	--	--	<0.001	--	--	<0.001	--	--	<0.001	--	--
[5]$LSD_{0.05}$	0.18	--	--	0.35	--	--	11.8	--	--	1.23	--	--

1 OARDC Seed-Source Accession/Identification Number.
2 Taper = height/width of tree.
3 Ranking in array of means (from lowest to highest) for individual seed sources for trait indicated.
4 pF: probability of statistical significance for analysis of variance F test.
5 $LSD_{0.05}$: Least Significant Difference at 5% probability level for comparing differences between locations and seed-source means.

Figure 6. Eleven-year heights of trees of SS 389 (Stone Coal Run, left) and SS 379 (Blister Run, right).

Differences Between Seed Sources

There was large variation in heights among trees of individual seed sources and between those of seed sources from the same stand collection. Average 11-year heights were tallest (3.99 m) for trees of SS-389 from Stone Coal Run, and trees of six other families from that area were also ranked among the one-third that were fastest growing, while none were among the one-third that were slowest growing. Trees of North Carolina SS-410 were slowest growing (2.97 m), and the other North Carolina origin, SS-24, was ranked third. Of the West Virginia origin trees, those of SS-379 from Blister Swamp were slowest growing (3.15 m); however, only one other source from that area was among the slowest-growing group, while trees of five families were among the top third (Tables 2, 3, 4; Figure 6).

For 11-year-old trees of the Blister Run families, six of 10 were among the slowest growing and only one was among the fastest. For Canaan Valley-State Park families, three of 10 were among the fastest growing and three were among the slowest, while for Canaan Valley-Cortland Road families, only one was among the fastest and four were among the slowest growing (Table 3).

Differences Within Seed Sources

In addition to the variation in heights of trees from different areas and between those of different seed sources, there was considerable variation within individual half-sib families from West Virginia and the two stand collections from North Carolina. Standard deviations in six-year heights were 28 to 48 percent of seed-source means, while for 11-year heights it was considerably lower, ranging from 12 to 30 percent of means (Table 2). The range in heights of individual trees of most half-sib families was great. For example, for SS-389, the fastest growing family in the study (3.99 m, s.d. 15% of

Table 3. Summary of Number of Seed Sources Ranked in the Top and Bottom One-Third of Half/Sib Families (West Virginia) and Stand Collections (North Carolina)[1].

Trait	No. SS in Top One-Third						No. SS in Bottom One-Third					
	Blr. Run (10)	Blr. Swp (10)	Stn Coal (10)	CV SP (10)	CV CR (8)	NC (2)	Blr. Run (10)	Blr. Swp (10)	Stn Coal (10)	CV SP (10)	CV CR (8)	NC (2)
6-Yr height	3	4	3	7	1	0	4	2	2	1	5	2
11-Yr height	1	5	7	3	1	0	6	2	0	3	4	2
Taper	4	5	5	1	2	0	2	2	0	6	6	2
Needle length	1	1	4	5	6	0	6	5	3	1	0	2
Lateral limbs	4	2	3	4	4	0	3	4	3	2	3	2
Branch angle	1	4	7	3	2	0	5	2	0	4	3	2
Shape	2	7	5	1	0	2	3	0	1	6	7	0
Density	1	6	8	2	0	0	4	1	0	6	4	2
Top needle color	5	2	5	3	2	0	1	7	1	4	3	2
Bottom needle color	8	4	1	0	1	2	1	1	5	4	6	0
Overall tree color	4	2	6	4	1	0	1	6	2	4	3	0
Bd brk 5/14	6	4	1	5	2	0	1	1	5	4	4	2
Bd brk 5/22	6	4	1	5	1	0	1	1	6	3	4	2
Bd brk 5/29	6	5	0	5	1	0	1	1	4	4	3	2

[1] Numbers of seed-source collections for each area are indicated in parenthesis below the location name

mean), the range in 11-year heights of individual trees was from 2.2–4.8 m, and for SS-379, the slowest growing (3.15 m, s.d. 22% of mean) of the West Virginia origins, the range was from 2.0–4.4 m (Table 2).

Tree Taper

Differences Between Locations

Average taper of trees (height/width, with larger values indicating "narrower" crowns) from different collection areas varied over a relatively small range; trees from the Blister Run, Blister Swamp, and Stone Coal Run areas had the narrowest crowns, averaging approximately 180 percent as tall as they were wide, while those from the Canaan Valley and North Carolina origins were "widest," approximately 170 percent as tall as wide (Table 2).

Differences Between Seed Sources

Of the 50 half-sib families and stand collections measured, trees of SS-384 from Stone Coal Run had the narrowest crowns (195%), with

Figure 7. Taper of 14-year-old trees of SS 419 (Canaan Valley-Cortland Road, left) and SS 384 (Stone Coal Run, right).

five of 10 from that area among the top one-third of families with the narrowest taper and none among the one-third that were widest. The three families (SS-419, 416, and 425) having the widest trees all came from the Canaan Valley-Cortland Road collection, and trees of three other seed sources were also among the widest group (Figure 7).

Trees of four Blister Run families were among those having the most narrow crowns, and two were among the widest; for Blister Swamp, trees of five families were among the most narrow one-third, and two were among the widest. For trees of Canaan Valley-State Park families, one was among the narrowest group, and six were among the widest. Trees of the two North Carolina stand collections were relatively wide, ranking 14th and 20th of the 50 seed sources (Tables 2, 3, 4).

Differences Within Seed Sources

As noted for tree heights, there was also considerable variation in tree taper within seed sources. For the 48 West Virginia collections, standard deviations varied from 8 to 22 percent of individual seed-source means (Table 2), while the range in tapers of individual trees was considerably greater. For SS-384 for which crowns of trees were most narrow, the range in tapers was from 150 to 270 percent, while for SS-419 having the widest crowns, the range was from 120 to 180 percent (Table 2; Figure 8).

Needle Lengths

Although needle lengths were measured on six-year-old trees in 1990 and 11-year-old trees in 1995, detailed measurement are presented for the 1995 measurements only.

Figure 8. Variation in taper and density of individual 14-year-old trees of SS 393 (Stone Coal Run).

Differences Between Locations

Average needle lengths measured on lateral limbs of trees in 1995 were significantly shorter on the North Carolina origins (14.7 mm) than those for the five West Virginia origins, which had average needle lengths of 18–19 mm (Table 2).

Differences Between Seed Sources

In general, differences in needle lengths of trees did not vary as greatly between half-sib families of the West Virginia origins of balsam fir as did taper and tree heights. Longest needles, 21.5 mm, were recorded for trees of SS-390 from Stone Coal Run, and needles of three other families from that area were also among the longest one-third, while three were among the one-third that were shortest, including SS-393, which had the shortest needles (16.5 mm) of all of the West Virginia origins (Tables 2, 3, 4).

Needles of trees from Blister Run families ranged from 17.0 to 19.1 mm in length, with only one having needles among the one-third that were longest, and six among the group that were shortest. For Blister Swamp families, needle lengths ranged from 17.1 to 18.8 mm, with five being among the shortest and one among the longest. As a group, trees of families of the two Canaan Valley collections were similar; only one (SS-402) was among the group having the shortest needles, while five from the State Park and six from Cortland Road were among those having the longest needles. Needles of trees of the two North Carolina collections ranked as the two shortest of all seed sources (Tables 2, 3, 4; Figure 9).

Table 4. Top- and Bottom-Ranked Individual Seed Sources for Different Tree Traits of Half-Sib Families (West Virginia) and Stand Collections (North Carolina).

Trait	Highest Ranked Seed Source				Lowest Ranked Seed Source			
	All Sources		W.V. Sources		All Sources		W.V. Sources	
	SS No.	Loc[1]	SS No.	Loc[1]	SS No.	Loc[1]	SS No.	Loc[1]
6-Yr height	389	SCR	389	SCR	410	NC	353	BR
11-Yr height	389	SCR	389	SCR	410	NC	379	BS
Taper	384	SCR	384	SCR	419	CVCR	419	CVCR
Needle length	390	SCR	390	SCR	24	NC	394	SCR
Lateral limbs	361	BR	361	BR	387	SCR	387	SCR
Branch angle	390	SCR	390	SCR	24	NC	419	CVCR
Shape	384	SCR	384	SCR	416	CVCR	416	CVCR
Density	384	SCR	384	SCR	425	CVCR	425	CVCR
Top needle color	387	SCR	387	SCR	368	BS	368	BS
Bottom needle color	24	NC	356	BR	416	CVCR	416	CVCR
Overall tree color	387	SCR	387	SCR	416	CVCR	416	CVCR
Bd brk 5/14	398	CVSP	398	CVSP	410	NC	361	BR
Bd brk 5/22	364	BR	364	BR	24	NC	361	BR
Bd brk 5/29	364	BR	364	BR	410	NC	361	BR

[1] Location of Seed Sources. BR = Blister Run, BS = Blister Swamp, SCR = Stone Coal Run, CVSP = Canaan Valley-State Park, CVCR = Canaan Valley-Cortland Road, NC = North Carolina

Results of needle-length measurements made in 1990 are not reported here, but comparisons between 1990 and 1995 needles showed that the average for all sources was only about 1 mm longer in 1995 than in 1990, and lengths on individual trees were highly correlated ($r = 0.82$, probability < 0.001).

Differences Within Seed Sources

Although the variation in standard deviations for needle lengths was relatively small, ranging from only 8 to 17 percent of seed-source means, there were individual trees having relatively large deviations from the average (Table 2). For example, there was approximately a two-fold (100 percent) difference in needle lengths of individual trees for seed sources having both the longest (SS-390) and shortest (SS-394) needles (Figure 9).

Numbers of Lateral Limbs

Differences Between Locations

The number of lateral limbs that develop on terminal shoots of trees can affect the density of trees and the length to which leaders can be cut

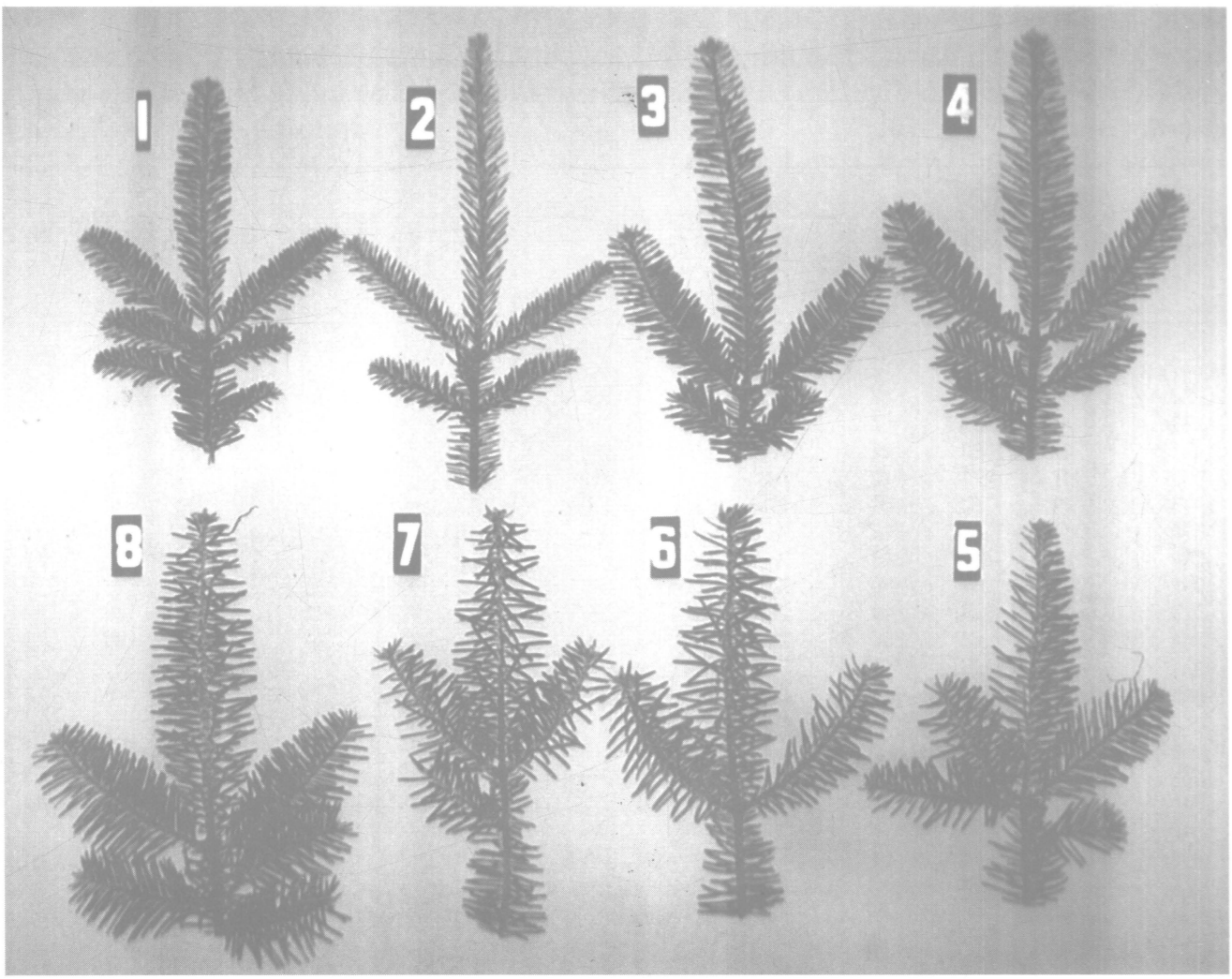

Figure 9. Variation in needle lengths and configuration on individual trees and seed sources: 1 = SS 4101, North Carolina; 2 = SS 363, Blister Run; 3 = SS 366, Blister Swamp; 4 = SS 393, Stone Coal Run; 5 = SS 416, Canaan Valley-Cortland Road; 6 = SS 372, Blister Swamp; 7 = SS 398, Canaan Valley-State Park; 8 = SS 390, Stone Coal Run.

when trees are sheared. For trees of the six seed-collection areas, numbers of lateral limbs on six-year-old trees were significantly lowest (7.0) for the North Carolina origins and ranged from 9.3 to 10.8 for West Virginia source trees (Table 5). In other studies, smaller numbers of lateral limbs were noted on North Carolina than on Canaan Valley, West Virginia, trees [Brown 1983, Brown and Heiligmann (unpublished data); Figure 10].

Differences Between Seed Sources

For trees of the West Virginia families, numbers of lateral limbs were greatest (13.9) on trees of SS-361 from Blister Run and lowest (6.5) on trees of SS-387 from Stone Coal Run. For the different areas, Blister Run and both Canaan Valley collections had four trees among the one-third having the most lateral limbs, while Stone Coal Run had three and Blister Swamp two. Of families having the smallest number of limbs, three were from Blister Run, four from Blister Swamp, four from Stone Coal Run, two from Canaan Valley-State Park, three from Canaan Valley-Cortland Road, and both North Carolina sources (Tables 3, 4, 5).

Differences Within Seed Sources

Of all the traits measured in this study, numbers of lateral limbs showed the largest variation in measurements between trees of the

Table 5. Means, Standard Deviations, and Ranking of Lateral Limbs, Branch Angle, Density, and Shape of Trees of Individual Half-Sib Families (West Virginia) and Stand Collections (North Carolina).

SS No.[1]	Lat. Lmbs.[2]			Top Branch Ang.[3]			Tree Shape			Tree Density[5]		
	Mean No.	S.D. % Mean	Rk[4]	Mean °	S.D. % Mean	Rk[4]	Mean Rtng[5]	S.D. % Mean	Rk[4]	Mean Rtng[6]	S.D. % Mean	Rk[4]
Blister Run, WV												
350	13.2	36	47	28.3	39	38	1.89	28	13	1.50	28	20
351	7 7	73	7	23 3	37	9	2 25	22	35	1.56	22	24
352	12 5	82	45	26 9	31	29	2.15	27	30	1.65	24	35
353	10.2	71	27	30 7	24	45	2.00	23	21	1.25	26	3
355	13.6	60	49	27.6	27	35	2.12	23	28	1.50	28	21
356	10.0	80	25	28.8	30	40	1.98	33	20	1.39	29	12
360	10.1	68	26	25 8	30	22	1.89	33	12	1.64	27	31
361	13.9	67	50	33.4	28	48	2.19	20	32	1.47	23	16
363	8.5	64	14	26.2	35	26	2.33	23	42	1.64	40	32
364	8.3	65	10	27.1	31	32	1.84	26	10	1.39	20	11
Mean	**10.8**	**21**	**6**	**27.7**	**32**	**5**	**2.06**	**8**	**3**	**1.50**	**9**	**3**
Blister Swamp, WV												
366	9.4	67	19	25.0	46	18	2.31	21	39	1.56	37	25
367	8.1	88	9	23.7	39	12	2.34	31	43	1.91	27	45
368	7.7	95	6	26.3	38	27	2.35	27	45	1.68	17	37
369	7.5	68	5	25.3	29	20	2.34	24	44	2.00	26	48
372	10.6	73	33	30.2	32	44	2.09	27	25	1.70	29	39
373	9.5	67	20	22.9	33	5	2.25	25	34	1.72	34	40
375	7.9	72	8	29.4	44	41	2.35	23	46	1.65	25	34
378	11.3	74	39	24.3	41	15	2.07	21	24	1.33	32	8
379	11.2	92	38	26.9	37	30	1.97	35	19	1.58	30	28
380	9.7	81	22	22.2	32	4	2.33	27	41	1.66	42	33
Mean	**9.3**	**15**	**2**	**25.7**	**38**	**2**	**2.24**	**6**	**5**	**1.68**	**11**	**5**
Stone Coal Run, WV												
381	9.8	99	23	24.2	33	14	2.26	20	36	1.74	28	41
384	10.2	71	28	23.2	28	7	2.61	20	50	2.13	23	50
385	9.0	73	16	20.7	37	3	1.83	42	9	1.67	29	36
386	9.4	67	18	24.5	39	17	2.30	23	40	1.79	28	43
387	6.5	85	1	26.0	37	23	2.14	27	29	1.64	32	30
389	13.5	75	48	24.3	34	15	2.23	32	33	1.90	36	44
390	10.6	81	35	19.0	39	1	2.45	22	48	2.05	29	49
393	12.5	66	46	23.0	45	6	2.29	29	37	1.93	26	46
394	7.5	68	4	26.0	32	23	2.11	29	27	1.75	31	42
395	10.5	67	31	26.2	35	25	1.95	28	18	1.58	24	27
Mean	**10.0**	**21**	**3**	**23.7**	**36**	**1**	**2.22**	**10**	**4**	**1.81**	**10**	**6**
Canaan Valley, State Park, WV												
397	10.3	82	29	29.5	26	42	1.82	39	7	1.42	26	14
398	10.6	64	32	23.4	29	11	2.06	31	23	1.59	30	29
399	10.6	49	34	25.7	32	21	1.83	32	8	1.48	40	17
400	11.9	55	41	29.5	37	43	1.74	36	4	1.29	31	6
402	9.8	72	24	28.4	30	39	1.70	41	3	1.25	34	2
403	12.5	77	44	27.1	37	33	1.94	21	16	1.47	27	15

Table 5 (continued). Means, Standard Deviations, and Ranking of Lateral Limbs, Branch Angle, Density, and Shape of Trees of Individual Half-Sib Families (West Virginia) and Stand Collections (North Carolina).

SS No.[1]	Lat. Lmbs.[2]			Top Branch Ang.[3]			Tree Shape			Tree Density[5]		
	Mean No.	S.D. % Mean	Rk[4]	Mean °	S.D. % Mean	Rk[4]	Mean Rtng[5]	S.D. % Mean	Rk[4]	Mean Rtng[6]	S.D. % Mean	Rk[4]
404	9.3	89	17	27.7	34	36	2.02	31	22	1.42	25	13
406	9.6	69	21	25.2	42	19	1.93	36	15	1.57	35	26
408	8.3	84	11	20.2	38	2	2.30	30	38	1.98	26	47
409	11.8	61	40	23.2	38	8	2.17	35	31	1.69	24	38
Mean	**10.5**	**12**	**5**	**25.9**	**26**	**3**	**1.95**	**10**	**2**	**1.52**	**14**	**4**
Canaan Valley, Cortland Road, WV												
416	8.5	82	13	26.4	22	28	1.67	34	1	1.50	25	18
417	12.2	86	42	27.1	31	33	1.81	36	6	1.29	31	7
418	11.2	73	37	27.8	37	37	1.94	26	17	1.53	31	23
419	8.7	80	15	35.0	22	49	1.68	36	2	1.26	5	4
424	10.8	91	36	23.9	44	13	1.85	31	11	1.38	0	10
425	10.4	63	30	31.2	31	47	1.79	36	5	1.25	21	1
426	8.4	99	12	27.0	32	31	1.91	24	14	1.50	27	19
428	12.2	84	43	23.3	48	9	2.09	30	26	1.52	36	22
Mean	**10.3**	**18**	**4**	**27.4**	**35**	**4**	**1.84**	**13**	**1**	**1.41**	**9**	**2**
Roan Mountain, NC												
24	7.0	37	2	41.1	17	50	2.39	18	47	1.28	34	5
410	7.0	98	3	31.0	24	46	2.47	18	49	1.35	24	9
Mean	**7.0**	**24**	**1**	**36.5**	**24**	**6**	**2.43**	**2**	**6**	**1.32**	**5**	**1**
Variable Mean	**10.0**	—	—	**28.4**	—	—	**2.09**	—	—	**1.58**	—	—
Mean Comparisons Between Locations												
[7]pF	0.003	—	—	<0.001	—	—	<0.001	—	—	<0.001	—	—
[8]$LSD_{0.05}$	2.42	—	—	3.65	—	—	0.23	—	—	0.21	—	—
Mean Comparisons Among Seed Sources Within Location												
[7]pF	<0.001	—	—	<0.001	—	—	<0.001	—	—	<0.001	—	—
[8]$LSD_{0.05}$	4.08	—	—	4.98	—	—	0.33	—	—	0.26	—	—

[1] OARDC Seed-Source Accession/Identification Number.
[2] Number of lateral limbs on terminal shoot.
[3] Top Branch Angle: average angle between terminal shoot on trees and ascending branches in uppermost whorl of limbs.
[4] Ranking in array of means (from lowest to highest) for indivdual seed sources for trait indicated.
[5] Tree Shape Ratings: 1 = Irregular; 2 = Moderately Irregular; 3 = Conical.
[6] Tree Density Ratings: 1 = Light; 2 = Moderate; 3 = Dense.
[7] pF: probability of statistical significance for analysis of variance F test.
[8] LSD: Least Significant Difference at 5% probability level for comparing differences between location and seed-source means.

Figure 10. Lateral limbs between major whorls on trees of SS 361 (Blister Run, left) and SS 24 (North Carolina, right).

same seed source. Standard deviations ranged from 36 to 99 percent of half-sib family means; for trees with the highest (SS-361) and lowest (SS-387) averages, actual numbers ranged from 10 to 33 and 5 to 24, respectively (Table 5). Similar tree-to-tree variation in numbers of lateral limbs has been noted in other studies with Canaan Valley and Roan Mountain, North Carolina, origins of balsam fir [Brown 1983, Brown 1998, Brown and Heiligmann (unpublished data)].

Lateral Branch Angle

Trees with ascending branch angles have a number of potential advantages for use as Christmas trees. The upswept limbs tend to cover the terminal shoot, generally making for a more conical and dense-appearing tree. Additionally, they tend to cover a greater length of the central stem, making it possible to leave longer leaders during shearing, thereby reducing the time needed to produce marketable trees. Using an angle gauge, branch angles (in degrees from the vertical) were measured for the uppermost whorl of limbs.

Differences Between Locations

Average branch angles for trees of the five West Virginia origins ranged from 24 to 28 degrees and were significantly smaller than those of trees from North Carolina (37 degrees, Table 5).

Differences Between Seed Sources

Trees of SS-390 from Stone Coal Run had the smallest average branch angle (19.0°), while the branch angle was largest (41.1°) for trees of SS-24 from North Carolina. For the one-third of the collections having the smallest branch angles, seven were from Stone Coal Run, four

Figure 11. Branch angles of uppermost whorls of trees of SS 390 (Stone Coal Run, left) and SS 419 (Canaan Valley-Cortland Road, right).

from Blister Swamp, three from Canaan Valley-State Park, two from Canaan Valley-Cortland Road, and one from Blister Run. Trees of collections having the largest branch angles were Blister Run with five, Canaan Valley-State Park with four, Canaan Valley-Cortland Road three, and Blister Swamp and North Carolina two each (Tables 3, 4, 5; Figure 11).

Differences Within Seed Sources

The variation in branch angles within individual families/collections was generally large. Standard deviations ranged from 17 to 46 percent of individual family means, with those for trees of the two North Carolina origins being the lowest (17 and 20 percent, Table 5). For individual trees of SS-390 having the smallest average branch angle (19°), the range in measurements was from 5 to 30°, and for SS-24 having the largest branch angle (41°), the range was from 30 to 55°.

Tree Shape

Tree shape/outline is an important factor contributing to the desirability/quality of Christmas trees. This trait is usually improved through shearing and shaping. However, having trees that are inherently conical would be very desirable and could reduce shearing costs. In this study, trees were subjectively evaluated for tree shape/outline using a three-point rating system: 1 = irregular, 2 = moderately irregular, and 3 = conical.

Differences Between Locations

The average shape of trees of the North Carolina origin was significantly best (2.4 — moderately conical to conical), while it was poorest (1.8 — slightly below the moderately irregular rating) for trees of the Canaan Valley-Cortland Road families. For trees of the other four West Virginia collection areas, average

Figure 12. Conical (SS 384, Stone Coal Run, left) and irregular (SS 416, Cortland Road, right) shapes of 14-year-old trees.

shape ranged from 2.0 to 2.2 — at or slightly above the moderately irregular rating (Table 5).

Differences Between Seed Sources

Of the 50 families/stand collections, average shape was best (2.61) for trees of SS-384 from Stone Coal Run, and five of 10 trees from that area were among the top one-third evaluated. For other areas, seven seed sources from Blister Swamp, both North Carolina sources, two from Blister Run, and one from Canaan Valley-State Park were among the top ranked. Trees of SS-416 had the poorest average shape (1.67), and trees of all but one of the eight families from that area were included in the lowest-ranked group, while six from Canaan Valley-State Park, three from Blister Run, and one from Stone Coal Run were in the lowest-rated group (Tables 3, 4, 5; Figure 12).

Differences Within Seed Sources

As noted for other variables, differences in tree shape within individual collections were relatively large. Standard deviations ranged from 18 to 42 percent of seed-source means, with trees of the two North Carolina collections both at 18 percent (Table 5). For trees of SS-384, which had the best average, the range in ratings for individual trees was from 2.0 (moderately irregular) to 3.0 (conical), while for those of SS-416, which had the poorest average rating, the range was from 0.5 (very irregular) to 2.5 (moderately irregular to conical) (Figure 8).

Tree Density

Tree density is another important factor affecting the quality of Christmas trees and is also one that is improved through shearing and shaping. Having trees that are inherently dense would be very helpful and, as with tree shape, could help reduce shearing and shaping costs. In this study, trees were subjectively rated for density using a three-point scale: 1 = open, 2 = medium, and 3 = dense.

Differences Between Locations

Trees of the Blister Swamp (1.68) and Stone Coal Run (1.81) half-sib families had the best densities, near the medium rating. Trees of the North Carolina stand collections had the lowest rating (1.32), followed closely by those from Canaan Valley-Cortland Road (1.41) and Canaan Valley-State Park and Blister Run (1.52) (Table 5).

Differences Between Seed Sources

Best average density (2.13) was found for trees of SS-384 from Stone Coal Run. Eight of 10 trees from that area were among the one-third of families having the best ratings, and none were in the lowest one-third. Trees from the Blister Swamp collection also rated relatively high for density, with six of 10 being in the top-rated group and only one in the lowest-rated (Tables 3, 4, 5).

Trees of SS-425 from Canaan Valley-Cortland Road had the lowest density rating (1.25), and four of eight trees from that area were among the lowest-ranked group, and none were among the highest-rated. Trees of both seed sources from North Carolina were also among the lowest-rated group. For Blister Run trees, only one half-sib family was among the highest-ranked group, while four were among the poorest; for Canaan Valley-State Park, two families were among the top one-third, and six

Figure 13. Dense (SS 384, Stone Coal Run, left) and open (SS 416, Canaan Valley-Cortland Road, right) densities of 14-year-old trees.

were among the bottom third (Tables 3, 4, 5; Figure 13).

Differences Within Seed Sources

Standard deviations for density ratings of individual trees varied from 17 to 42 percent of individual seed-source means (Table 5). For individual trees of SS-384 which were highest-rated (2.6, medium to dense), the range was from 1.5 to 3.0 (moderately open to dense, Figure 9), while for SS-425, having the most open trees (1.2, open), the range was from 0.5 (very open) to 1.5 (moderately open) (Figure 8).

Upper-Surface Needle Color

During February 1996 and January 1997, evaluations were made of the color of the upper surfaces of needles of trees. A subjective rating system of 1 = yellow, 2 = green/yellow, 3 = yellow/green, 4 = green, and 5 = blue/green was used. In making comparisons, a sample from a single tree that was judged to have yellow/green foliage (rating 3.0) was compared with each individual tree in the planting, and a rating given based on the extent to which foliage color was better or poorer. Detailed data are presented for the 1996 ratings.

Differences Between Locations

Ratings were lowest (3.4, yellow/green to green) for North Carolina trees and best (3.8, near the green rating) for those from Blister Run and Stone Coal Run. Ratings of trees from Blister Swamp (3.5) and the two Canaan Valley origins (3.6) were at the yellow/green to green level (Table 6).

Differences Between Seed Sources

Average color of the upper surfaces of needles was best (4.17) for trees of SS-387 from Stone Coal Run. Four other families from that area also had ratings that were in the top one-third, while only one was in the bottom third. Families from Blister Run also had trees with relatively good upper-surface colors, with five of the top-rated trees being from that area and only one among the poorest-rated. Trees of SS-368 from Blister Swamp had the poorest rating (3.02), and seven of 10 trees from that area were among the one-third lowest-rated and two among the top group. Trees of both North Carolina collections were in the lowest-rated group. For Canaan Valley-State Park sources, three were in the top-ranked group and four in the bottom-ranked, while for Canaan Valley-Cortland Road collections, two were top-ranked seed sources, and three were in the lowest one-third (Tables 3, 4, 6).

Details of upper-surface needle color evaluations made in 1997 are not presented here. However, comparisons between evaluations showed that although ratings were slightly higher in 1997 (overall average of 3.70) than in 1996 (overall average of 3.61), ratings for individual trees were highly correlated ($r = 0.78$, probability < 0.001).

Differences Within Seed Sources

Standard deviations for upper-surface needle colors varied from 13 to 35 percent of individual seed-source means and was greatest for the two North Carolina origins (Table 6). For the West Virginia sources, the range in ratings for individual trees of SS-387, the most highly rated, were from 3.5 (yellow/green to green) to 5.5 (blue green to bluish), while for the lowest-rated family (SS-368), ratings ranged from 1.4 (yellow to green/yellow) to 4.5 (green to blue/green).

Lower-Surface Needle Color

The lower surface of needles of trees, particularly as influenced by the number and coloration of stomatal bands, can have a distinct influence on the appearance of trees. During February 1996 and January 1997, subjective ratings were made of the lower surfaces of needles of trees as follows: 1 = gray, 2 = moderately bluish, 3 = bluish. As had been used for upper surfaces of needles, a sample from a single tree that was judged to have moderately bluish (rating 2.0) lower foliage color was compared with each individual tree in the planting and a rating given based on the extent to which color was better or poorer. Detailed data are presented for the 1996 ratings.

Differences Between Locations

Trees of the North Carolina origins had the best ratings for color of the lower surfaces of

Table 6. Means, Standard Deviations, and Ranking of Foliage Colors/Tree Appearance of Individual Half-Sib Families (West Virginia) and Stand Collections (North Carolina).

SS No.[1]	Upper Surface Color of Needles			Lower Surface Color of Needles			Overall Color/ Appearance of Tree		
	Mean Rtng[3]	S.D. % Mean	Rank[2]	Mean Rtng[4]	S.D. % Mean	Rank[2]	Mean Rtng[5]	S.D. % Mean	Rank[2]
Blister Run, WV									
350	3.58	23	21	2.76	13	42	2.76	26	30
351	3.76	21	37	2.76	18	41	2.67	21	24
352	3.98	14	47	2.89	15	45	3.06	22	45
353	3.70	21	33	2.75	18	39	2.78	27	33
355	3.69	19	31	2.92	13	46	2.73	24	28
356	3.82	17	43	2.98	14	48	2.89	23	40
360	3.94	18	45	2.73	12	38	3.10	30	48
361	3.68	24	30	2.93	14	47	2.78	26	32
363	3.82	17	42	2.55	24	21	3.14	19	49
364	3.52	16	17	2.42	21	10	2.48	22	13
Mean	**3.75**	**4**	**5**	**2.77**	**6**	**5**	**2.84**	**7**	**6**
Blister Swamp, WV									
366	3.39	26	11	2.68	19	32	2.53	33	15
367	3.37	21	9	2.58	12	25	2.45	28	9
368	3.02	25	1	2.48	20	16	2.13	34	2
369	3.31	21	6	2.61	18	28	2.47	27	12
372	3.33	25	7	2.52	19	19	2.44	22	8
373	3.48	20	16	2.57	16	24	2.55	25	17
375	3.62	20	24	2.69	15	34	2.79	25	34
378	3.61	19	3	2.72	12	37	2.59	32	20
379	3.70	18	34	2.83	12	44	2.75	25	29
380	3.93	15	44	2.70	15	36	2.89	23	41
Mean	**3.48**	**7**	**2**	**2.64**	**3**	**4**	**2.56**	**8**	**2**
Stone Coal Run, WV									
381	3.56	25	20	2.75	15	40	2.56	30	18
384	3.59	22	22	2.48	21	15	2.65	28	23
385	4.06	20	49	2.58	18	27	3.08	23	47
386	3.65	20	27	2.57	11	22	2.98	22	43
387	4.17	13	50	2.69	12	33	3.19	19	50
389	3.96	17	46	2.65	15	30	3.08	21	46
390	3.52	15	18	2.28	21	2	2.52	25	14
393	3.76	16	39	2.46	17	12	2.83	18	39
394	3.43	24	15	2.41	16	8	2.33	37	6
395	3.76	19	38	2.48	20	17	2.83	22	38
Mean	**3.76**	**6**	**6**	**2.54**	**5**	**2**	**2.80**	**10**	**5**
Canaan Valley-State Park, WV									
397	3.43	22	14	2.66	15	31	2.45	27	11
398	3.65	22	26	2.41	17	6	2.76	24	31
399	3.33	21	8	2.52	18	18	2.31	28	5
400	3.25	28	4	2.46	18	13	2.31	37	4
402	3.77	19	41	2.54	20	20	2.81	21	36
403	3.65	23	28	2.41	20	7	2.83	27	37

Table 6 (continued). Means, Standard Deviations, and Ranking of Foliage Colors/Tree Appearance of Individual Half-Sib Families (West Virginia) and Stand Collections (North Carolina).

SS No.[1]	Upper Surface Color of Needles			Lower Surface Color of Needles			Overall Color/ Appearance of Tree		
	Mean Rtng[3]	S.D. % Mean	Rank[2]	Mean Rtng[4]	S.D. % Mean	Rank[2]	Mean Rtng[5]	S.D. % Mean	Rank[2]
404	3 78	19	40	2.79	14	33	2.92	26	42
406	3 52	20	19	2.57	16	23	2.81	20	35
408	3 39	19	10	2.41	23	9	2.54	28	16
409	3 74	18	36	2.62	15	29	2.69	25	26
Mean	**3.55**	**5**	**3**	**2.54**	**5**	**2**	**2.64**	**8**	**4**
Canaan Valley-Cortland Road, WV									
416	3.06	20	2	2.14	25	1	2.11	24	1
417	3.74	18	35	2.29	19	3	2.69	25	25
418	3.70	18	32	2.70	14	35	2.72	29	27
419	3.21	17	3	2.40	22	5	2.38	26	7
424	3.67	22	29	2.43	19	11	2.60	35	21
425	3.64	17	25	2.33	15	4	2.64	24	22
426	3.41	20	12	2.48	15	14	2.45	19	10
428	4.00	16	48	2.58	16	26	3.00	29	44
Mean	**3.55**	**9**	**3**	**2.42**	**7**	**1**	**2.57**	**10**	**3**
Roan Mountain, NC									
24	3.29	28	5	3.33	11	49	2.25	40	3
410	3.43	35	13	3.30	9	50	2.57	27	19
Mean	**3.36**	**3**	**1**	**3.31**	**1**	**6**	**2.41**	**9**	**1**
Variable Mean	**3.61**	—	—	**2.62**	—	—	**2.68**	—	—
Mean Comparisons Between Locations									
[5]pF	0.027	—	—	<0.001	—	—	0.031	—	—
$LSD_{0.05}$	0.30	—	—	0.19	—	—	0.32	—	—
Mean Comparisons Among Individual Seed Sources									
[5]pF	<0.001	—	—	<0.001	—	—	<0.001	—	—
[6]$LSD_{0.05}$	0.41	—	—	0.24	—	—	0.39	—	—

[1] OARDC Seed-Source Accession/Identification Number.
[2] Upper Surface Needle Color Rating: 1 = Yellow; 2 = Green-Yellow; 3 = Yellow-Green; 4 = Green; 5 = Blue-Green.
[3] Lower Surface Needle Color Rating: 1 = Gray; 2 = Moderately "Bluish"; 3 = "Bluish."
[4] Overall/Color Appearance of Tree: 1 = Poor; 2 = Fair; 3 = Good; 4 = Excellent.
[5] pF: probability of statistical significance for analysis of variance F test.
[6] $LSD_{0.05}$: Least Significant Difference at 5% probability level for comparing differences between location and seed-source means.

needles, averaging 3.31, bluish to very bluish. For the West Virginia origins, trees from Blister Run were most highly rated (2.8, near the bluish), while those for Blister Swamp, Stone Coal Run, Canaan Valley-State Park, and Canaan Valley-Cortland Road had slightly-bluish to bluish ratings (2.4 to 2.6) (Table 6).

Differences Between Seed Sources

Trees of SS-24 from North Carolina were top-rated (3.33) for color of the lower surface of needles, followed closely (3.30) by those of SS-410, the other North Carolina source. Of the West Virginia trees, SS-356 from Blister Run was top-rated (2.98), and eight of 10 families from that area were among the third having the highest ratings, while only one was among the lowest one-third. Four of 10 families from Blister Swamp were among the highest-rated group, with one in the lowest-rated. Trees of families from the other three areas had not more than one top-rated seed source and had four to six in the lowest one-third (Tables 3, 4, 6).

Details for 1997 evaluations of lower-surface needle color are not presented here. However, comparisons between evaluations showed that although ratings were slightly lower in 1997 (overall average of 2.53) than in 1996 (overall average of 2.62), ratings were highly correlated ($r = 0.73$, probability < 0.001).

Differences Within Seed Sources

Individual trees of North Carolina origins had, by far, the least variation in lower-surface needle colors, with standard deviations of 9 and 11 percent of seed source means for the two collections and ranges in colors of 2.5 to 3.5 for individual trees of both seed sources. For West Virginia trees, standard deviations of individual seed sources ranged from 12 to 25 percent of seed-source means (Table 6). For the top-rated West Virginia origin (SS-356), the range in ratings of individual trees was from 2.0 to 3.5, while for the lowest-rated family (SS-416), ratings ranged from 1.5 to 3.0.

Overall Color/Appearance of Trees

In addition to rating the colors of the upper and lower surfaces of needles of trees, evaluations were made in February 1996 and January 1997 of the general color/appearance when the total tree was viewed from a distance of approximately 10–15 feet. For those ratings, a subjective scale was used, with 1 = poor, 2 = fair, 3 = good, and 4 = excellent. Detailed data are presented for the 1996 ratings.

Differences Between Locations

Ratings were highest for trees of the Blister Run and Stone Coal Run collections, with each having averages of 2.8, near the "good" rating, while ratings were poorest for North Carolina trees (2.4). Ratings were slightly better, 2.6, for trees of the Blister Swamp and two Canaan Valley sources (Table 6).

Differences Between Seed Sources

Of the individual half-sib families, trees of SS-387 from Stone Coal Run had the highest rating (3.19) and six of 10 families from that area were among the top third and two among the lowest-rated one-third. Trees of SS-416 from Canaan Valley-Cortland Road received the lowest rating (2.11), with two other families from that area among the lowest-rated and only one among the top third. Four Blister Run families were in the top-ranked group and one was in the lowest-ranked, while for Blister Swamp families, two were in the top-ranked and six in the lowest-ranked one-third. Canaan Valley-State Park collections were represented by four families in both the top- and bottom-ranked groups. For North Carolina collections, one was in the bottom one-third and none in the top (Tables 3, 4, 6).

Data is not presented for the January 1997 ratings of the overall appearance/color of trees. However, as noted for comparisons of upper surfaces, ratings were somewhat higher in 1997 (overall average of 2.82) than in 1996 (overall average of 2.68), but ratings for individual trees were highly correlated ($r = 0.69$, probability < 0.001).

Differences Within Seed Sources

Standard deviations in overall color/appearance of trees within individual seed sources ranged from 18 to 40 percent of seed-source means, with the least variation for SS-393 from Stone Coal Run and the highest for SS-24 from North Carolina (Table 6). For SS-387, top-ranked family for this trait, appearance of indi-

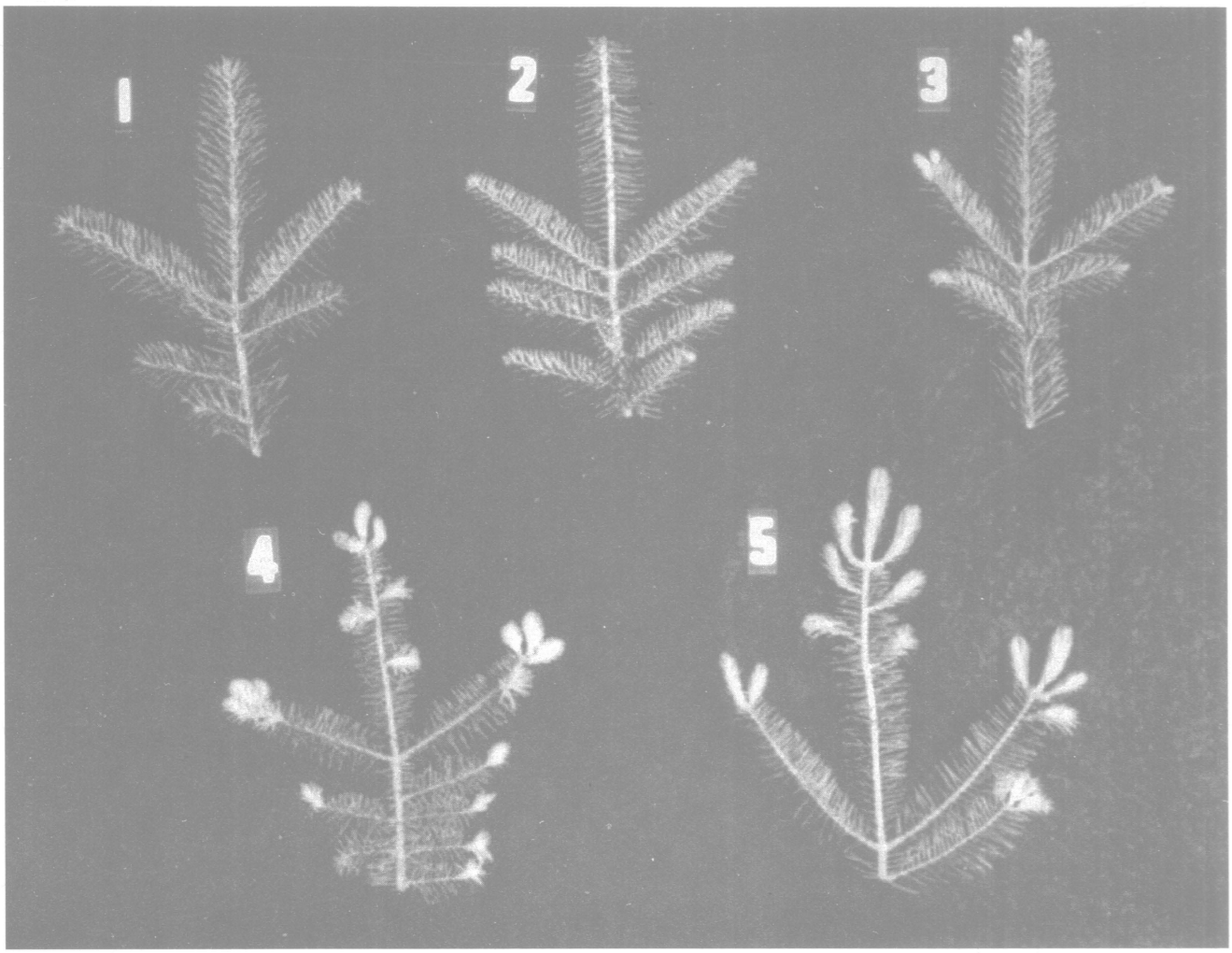

Figure 14. Stages of bud break on trees: 1 = tight, buds not swelling; 2 = buds swelling; 3 = slight exposure of new needles; 4 = major exposure of new needles; 5 = needles fully exposed.

vidual trees ranged from 2.0 to 4.0, and for the lowest ranked, SS-416, it ranged from 1.5 to 3.0.

Spring Bud Break

Foliage of single-needled conifers, including *Abies* sp., can be severely damaged if buds break dormancy and new foliage is exposed before the last frosts/freezes occur in the spring. Earlier studies found that trees of a Canaan Valley seed source of balsam fir broke dormancy somewhat later in the spring than did trees of a North Carolina (Fraser fir) origin and considerably later than Pennsylvania, New York, and Nova Scotia origins (Brown 1983, Brown 1998, Brown 1999). For this study, all trees in the experimental planting were rated for bud break and shoot development at weekly intervals from May 7 to May 29, 1996, and again in 1997, beginning on May 1 and continuing until May 29. In those ratings, a five-point scale was used: 1 = buds not expanded, 2 = buds swelling, 3 = minor foliage exposed, 4 = major foliage exposed, and 5 = foliage fully exposed (Figure 14). Details are presented for the May 14, 22, and 29, 1996, ratings. Evaluations for the May 1 rating are not included because buds on most trees showed little expansion, and there were only minor differences in observations.

Differences Between Locations

There were no significant differences (at the 5% probability level) in average bud develop-

Table 7. Means, Standard Deviations, and Ranking of Bud Break/Bud Development on Trees of Individual Half-Sib Families (West Virginia) and Stand Collections (North Carolina).

SS No.[1]	5/14/96 Mean Rtng[3]	5/14/96 S.D. % Mean	5/14/96 Rank[2]	5/22/96 Mean Rtng[3]	5/22/96 S.D. % Mean	5/22/96 Rank[2]	5/29/96 Mean Rtng[3]	5/29/96 S.D. % Mean	5/29/96 Rank[2]
Blister Run, WV									
350	2.10	9	17	2.67	13	13	3.57	14	12
351	2.12	6	21	2.81	9	24	3.83	14	22
352	2.06	8	12	2.69	24	15	3.59	15	13
353	2.11	10	19	2.73	12	19	3.72	13	19
355	2.03	13	4	2.54	15	4	3.48	12	5
356	2.08	9	13	2.70	13	16	3.68	13	15
360	2.14	12	25	2.92	13	28	3.92	14	26
361	2.41	16	49	3.19	17	48	4.40	17	48
363	2.09	16	15	2.70	15	16	3.65	14	14
364	2.00	6	1	2.29	13	1	3.03	16	1
Mean	**2.14**	**12**	**1**	**2.72**	**17**	**1**	**3.69**	**16**	**1**
Blister Swamp, WV									
366	2.04	12	7	2.59	15	7	3.50	16	6
367	2.03	13	4	2.57	12	6	3.40	11	3
368	2.08	10	13	2.66	18	12	3.68	18	15
369	2.05	13	10	2.65	19	8	3.51	16	8
372	2.11	13	30	2.87	15	27	4.00	15	29
373	2.16	16	28	2.84	18	26	3.92	16	26
375	2.13	17	23	2.78	20	23	3.91	16	25
378	2.35	20	46	3.17	18	46	4.35	16	47
379	2.12	17	21	2.78	16	22	3.89	15	24
380	2.13	12	23	2.75	17	20	3.70	19	17
Mean	**2.20**	**15**	**4**	**2.76**	**17**	**3**	**3.79**	**18**	**2**
Stone Coal Run, WV									
381	2.11	12	19	2.76	16	21	3.82	11	22
384	2.18	11	31	2.98	16	35	4.05	13	35
385	2.30	11	42	3.07	13	42	4.01	12	31
386	2.21	14	35	3.02	13	37	4.10	12	39
387	2.14	15	26	2.81	21	25	3.81	17	21
389	2.31	18	43	3.17	19	46	4.20	19	45
390	2.20	36	34	3.00	14	36	4.05	14	35
393	2.15	19	27	2.92	18	29	4.02	15	32
394	2.22	14	38	2.98	18	34	4.02	15	32
395	2.10	11	17	2.68	21	14	3.71	21	18
Mean	**2.19**	**15**	**3**	**2.94**	**15**	**5**	**3.98**	**17**	**5**
Canaan Valley-State Park, WV									
397	2.04	16	7	2.62	21	8	3.52	21	9
398	2.00	6	1	2.38	16	2	3.22	20	2
399	2.19	17	32	2.93	14	31	4.09	15	37
400	2.04	15	7	2.64	17	10	3.50	16	6
402	2.02	12	3	2.52	19	3	3.41	14	4
403	2.36	15	47	3.12	21	45	4.40	12	48
404	2.21	16	35	2.96	19	33	4.02	17	32

Table 7 (continued). Means, Standard Deviations, and Ranking of Bud Break/Bud Development on Trees of Individual Half-Sib Families (West Virginia) and Stand Collections (North Carolina).

SS No.[1]	5/14/96 Mean Rtng[3]	5/14/96 S.D. % Mean	5/14/96 Rank[2]	5/22/96 Mean Rtng[3]	5/22/96 S.D. % Mean	5/22/96 Rank[2]	5/29/96 Mean Rtng[3]	5/29/96 S.D. % Mean	5/29/96 Rank[2]
406	2.26	18	41	3.05	18	40	4.09	18	37
408	2.03	14	4	2.55	23	5	3.52	22	9
409	2.21	14	35	3.05	16	40	4.10	14	39
Mean	**2.14**	**15**	**1**	**2.78**	**19**	**4**	**3.79**	**20**	**2**
Canaan Valley-Cortland Road, WV									
416	2.09	17	15	2.71	16	18	3.75	16	20
417	2.32	20	44	3.11	18	44	4.00	12	29
418	2.19	15	32	2.94	14	32	4.00	12	29
419	2.24	17	40	3.04	21	38	4.12	17	41
424	2.04	8	10	2.64	9	10	3.54	9	11
425	2.22	11	38	3.04	16	39	4.13	17	42
426	2.16	19	28	2.93	16	30	3.93	15	28
428	2.33	13	45	3.09	17	43	4.17	13	43
Mean	**2.17**	**17**	**5**	**2.75**	**16**	**2**	**3.96**	**17**	**4**
Roan Mountain, North Carolina									
24	2.37	13	48	3.33	15	50	4.24	16	46
410	2.52	15	50	3.21	10	49	4.42	19	50
Mean	**2.45**	**13**	**6**	**3.27**	**19**	**6**	**4.33**	**19**	**6**
Variable Mean	**2.18**	—	—	**2.86**	—	—	**3.81**	—	—
Mean Comparisons Among Locations									
[4]pF	0.241	—	—	0.058	—	—	0.108	—	—
[5]$LSD_{0.05}$	—	—	—	—	—	—	—	—	—
Mean Comparisons Among Individual Seed Sources									
[4]pF	<0.001	—	—	<0.001	—	—	<0.001	—	—
[5]$LSD_{0.05}$	0.17	—	—	0.27	—	—	0.34	—	—

[1] OARDC Seed-Source Accession/Identification Number.
[2] Ranking in array of means (from lowest to highest) for seed sources for trait indicated.
[3] Bud Break Rating: 1 = Buds Tight (not swelling); 2 = Buds Swelling; 3 = Slight Exposure of New Needles; 4 = Major Exposure of New Needles; 5 = Needles Fully Exposed.
[4] pF: probability of statistical significance for analysis of variance F test.
[5] $LSD_{0.05}$: Least Significant Difference at the 5% probabililty level for comparing differences between location and seed source means.

ment of trees from different areas for the three evaluations reported, apparently because of wide variation between individual trees and seed sources within areas. On May 14, trees from all collections showed obvious signs of bud enlargement, with averages for the five West Virginia collections ranging from 2.14 to 2.20 and those from North Carolina averaging slightly higher at 2.45. By May 22, development of buds had progressed to the point where North Carolina origin trees were showing minor foliage exposure (rating 3.27), while average development for the five West Virginia origins had not progressed quite so far, with ratings of 2.72 to 2.94. On May 29 when the last set of evaluations was made in 1996, trees from all locations had progressed to the point where there was exposed foliage on trees of all seed sources from each area, with the average being highest for North Carolina trees (Table 7; Figure 14).

Differences Between Seed Sources

There were highly significant differences in bud development/bud break for individual seed sources for all times of evaluation. For all rating periods, trees of the two North Carolina collections had bud development that was at or near the most advanced, with rankings of 48 and 50, 50 and 49, and 46 and 50, for the three rating periods for SS-24 and SS-410, respectively. Of the West Virginia origins, trees of SS-361 from Blister Run showed the earliest bud development and foliage exposure for all three rating times; however, trees of six of 10 seed sources from that area were also among the one-third showing the slowest development, including SS-364 which was the slowest to develop for all ratings. As a group, approximately half of the trees from Blister Swamp collections were among the slowest developing and only one among the fastest, while approximately half of Stone Coal Run half-sib families were among the first to break dormancy and only one was among the slowest one-third (Tables 3, 4, 7; Figure 14).

A comparison of bud break/foliage exposure data for the May 14, 22, and 29, 1996, evaluations with those for May 15, 23, and 30, 1997, showed correlations of r = 0.76, 0.81, and 0.82, respectively, all of which were significant at less than the 0.001 probability level. Comparisons also showed that the appearance of new growth was somewhat earlier in 1996 than in 1997. Similar results were noted in another study in which evaluations were made between stand collections of balsam fir from Canaan Valley and Roan Mountain (Brown 1998).

Differences Within Seed Sources

Standard deviations within individual seed sources for time of bud break/foliage exposure ranged from 6 to 36 percent, 9 to 24 percent, and 9 to 22 percent, respectively, for the May 14, 22, and 29 dates (Table 7). For individual trees, stage of bud development for North Carolina trees ranged from 2.00 to 3.00 for the May 14 rating, 2.00 to 4.00 for May 22, and 2.50 to 5.00 for the May 29 date. For trees of SS-364, which were slowest to develop, ratings were 2.00 to 2.50 on May 14, 2.00 to 3.00 on May 22, and 2.00 to 4.00 on May 29. For SS-361, the earliest to develop, ratings were 2.00 to 3.00, 2.00 to 4.00, and 2.50 to 5.00, respectively, for the three rating periods.

Summary and Conclusions

As noted previously, the major purpose of this research was to study the variation in characteristics of trees from different stands and seed sources of balsam fir from the four locations in West Virginia where it occurs naturally. The two North Carolina/Fraser fir stand collections were included in the study to provide a reference for comparison to a widely accepted and planted variety/species. Since the North Carolina seed sources are stand collections rather than from individual trees (half-sib families) and also come from only one part (Roan Mountain) of the variety/species range, caution should be exercised in making broad conclusions about the relative performance of trees of var. *phanerolepis* from West Virginia and those of var. *fraseri.*

Results of measurements and subjective evaluations of different characteristics of trees made in this study emphasize the large variation associated with trees of balsam fir from the different locations in West Virginia, as well as

the variation related to differences between and within individual half-sib families.

Trees of Stone Coal Run half-sib families were highest-ranked for nine of the 14 traits evaluated, including those for total height, taper, branch angle, tree shape and density, the color of the upper surfaces of needles, and overall color (Table 4). In addition, for many of those traits, trees of several other families from that area were rated among the top one-third included in the study (Table 3). Conversely, for six of the 14 traits measured — taper, branch angle, shape, density, color of lower needle surfaces, and overall color — trees of half-sib families from Canaan Valley-Cortland Road were lowest-rated of the West Virginia families, and at least half from that area were among the one-third that were lowest-rated for eight of the 14 traits (Table 3).

Although none of the Blister Swamp families were top-ranked for any of the traits measured, half or more of the families from that area were among the top one-third in a number of characteristics of importance for Christmas trees, including height growth, taper, branch angle, shape, density, lower-surface needle color, and bud break. Individual families from that area were lowest-ranked for one particularly important characteristic, upper-surface needle color, with six of 10 trees from that area ranked in the bottom one-third of families and seven of 10 trees ranked in the lowest group for overall color (Tables 3, 4).

Trees of the Blister Run families were most outstanding for lower needle-surface color, with the top-ranked of the West Virginia families for that characteristic coming from that area and eight of 10 families in the highest-rated one-third; the top-ranked family for lateness in bud break also came from that area, and six of 10 were among the highest-ranked. Conversely, none of the Blister Run half-sib families were in the bottom one-third of the rankings for that trait (Tables 3, 4).

With the exception of one of the ratings for bud break, none of the half-sib families from Canaan Valley-State Park were top-rated for the different tree characteristics. Five of 10 families from that area were among the top one-third of seed sources for lateness of bud break, while four or more of the 10 sources were ranked in the bottom one-third group for taper, branch angle, shape, density, top and bottom needle color, overall tree color, and bud break for the May 29 rating (Tables 3, 4).

One characteristic not discussed in the previous summary is needle length of trees. Whether longer or shorter needles would be preferable is probably a matter of individual Christmas-tree grower and/or buyer perception. Average needle lengths of the two North Carolina seed sources were considerably shorter than those of the West Virginia origins, while variation in average lengths of those of the West Virginia sources from different areas was generally minimal.

Based on the previous results and discussions, it appears that major progress can be made in improving the characteristics of and reducing the variation in trees of the West Virginia origins of balsam fir used for Christmas trees. Trees of Stone Coal Run half-sib families were particularly outstanding in a number of characteristics of interest, while those of some of the families from the Blister Swamp source were excellent in two very important characteristics, form and density. Use of seed collected from those areas (or from trees for which those areas were the original source) could provide considerable improvement. Additionally, there were individual families from other areas that rated highly in certain traits. For example, trees from Blister Run rated highly for needle colors and bud break.

As noted in the introductory sections, *A. balsamea* var. *phanerolepis* is distinguished from var. *balsamea* primarily on the basis of differences in the relative lengths of the scales and bracts of cones of trees.

Results of studies reported here refer specifically to the West Virginia origins of balsam fir, and the results should not be interpreted as applicable to sources from other areas that may be identified as var. *phanerolepis* because other such sources were not included in the research.

Present and Future Improvement of Tree Characteristics

Steps for improving characteristics of trees of the West Virginia origins of balsam fir used for Christmas trees include:

- Collection of seed from specific "superior" phenotypes in native stands and seed-production areas.
- Thinning of existing seed-production areas (natural or planted) to trees having selected, more desirable characteristics (phenotypes).
- Establishment of seed orchards using clonal material from selected trees in natural and planted stands.
- Controlled pollination using selected male and female parents to provide seed for establishment of "improved" seed production areas.

At OSU/OARDC, three of these steps are being taken. In 1980, two seed production areas were established at the Pomerene Forest Laboratory near Coshocton, Ohio, using all of the trees of the Canaan Valley, West Virginia, origin of balsam fir that had been used in the original study that compared West Virginia, North Carolina, Pennsylvania, and New York origins of balsam fir (Brown 1983). Those trees, which represent a stand collection having natural genetic variation associated with trees from that area, are now producing viable seed for use by the nursery/Christmas tree industries. Plans are also being made to remove individual trees from those orchards that have less desirable tree and foliage characteristics.

The experimental planting at the USDA North Appalachian Experimental Watershed Laboratory used in the research reported here has been thinned from the original 1,200 to approximately 300 trees based on half-sib family performance and phenotypic characteristics of trees. This area will serve as an "improved" seed orchard, which will be a source of seed when appreciable quantities of viable seed are produced in approximately five to 10 years.

In addition, 55 individual trees — ortets — were selected in that orchard, again based on the best families and phenotypes. In March 1999, scions collected from those trees were grafted onto root-stock of Canaan Valley trees, and those trees will be used to establish a clonal seed orchard at OSU/OARDC at Wooster in the spring of 2000. In addition, root-stock was potted in April 1999 to use for additional grafts to be made in the springs of 2000 and 2001.

Efforts to establish new seed orchards, such as those being established at OARDC and at other locations, take on additional significance because of the presence of the balsam wooly adelgid/aphid *(Adelges picea)* in all of the natural stands of balsam fir in West Virginia. This pest has been responsible for decimation of many of the natural Fraser fir stands, and it is probable that the same fate is in store for the West Virginia populations. Mortality of individual trees is already occurring in most stands, and that is likely to accelerate as pest populations continue to build up.

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The Ohio State University
Ohio Agricultural Research and Development Center
1680 Madison Avenue
Wooster, Ohio 44691-4096
330-263-3700

In Partnership With
Ohio State University Extension
College of Food, Agricultural, and Environmental Sciences

The Ohio State University
Ohio Agricultural Research and Development Center
1680 Madison Avenue
Wooster, Ohio 44691-4096